N84-16248 UNCLAS

1.0 1.1 1.25 1.4 1.6 1.8 2.0 2.2 2.5 2.8 3.2 3.6 4.0 4.5 5.0 5.6

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS
STANDARD REFERENCE MATERIAL 1010a
(ANSI and ISO TEST CHART No. 2)

(NASA-CR-175341) RELIABILITY ISSUES IN ACTIVE CONTROL OF LARGE FLEXIBLE SPACE STRUCTURES Semiannual Status Report, 16 May - 15 Nov. 1983 (Massachusetts Inst. of Tech.) 8 p HC A02/MF A01 CSCL 22B G3/18

N84-16248

Unclas 15273

RELIABILITY ISSUES IN ACTIVE CONTROL OF LARGE FLEXIBLE SPACE STRUCTURES

Semi-Annual Status Report

for the period

May 16, 1983 to November 15, 1983

NASA Research Grant No. NAG1-126

Principal Investigator: Prof. W.E. Vander Velde
Department of Aeronautics and Astronautics
Massachusetts Institute of Technology
Cambridge, MA 02139

November 23, 1983

RELIABILITY ISSUES IN ACTIVE CONTROL OF LARGE FLEXIBLE SPACE STRUCTURES

Introduction

This is the report of the status of work under NASA Research Grant No. NAG1-126 for the period May 16, 1983, to November 15, 1983. The research sponsored by this grant is focussed on the problem of unreliability of control system components and the various aspects of our attempt to deal with that problem. This matter, which is important in many applications, is of obvious concern in large space structure control because of the large number of components required to achieve specified performance in some situations, and the long operating period required between maintenance visits. The critical role of component unreliability in limiting the performance of complex control systems seems not to be widely recognized, but partly through the stimulus of this grant the message is being heard in some quarters. One evidence of this is that the Principal Investigator has just been invited to present a "statement of the problem" paper on Uncertainty Management - which is defined to include the management of failures - at the next Workshop on Identification and Control of Large Space Structures sponsored by NASA Headquarters, JPL, and Langley Research Center.

Research Progress

During this reporting period, work was centered on two tasks: the detection and isolation of component failures during system operation, and algorithms for reconfiguring control systems following detection and isolation of a failure.

Almost all of the research on FDI reported in the literature addresses the problem of detecting and isolating component failures in the presence of random disturbances and sensor noise. But

experience suggests that wideband noise is rarely the principal source of difficulty in detecting failures. In the writer's previous work on velocity control systems for advanced guideway vehicles, the major problem was low frequency unmodeled effects like running up hill or into a headwind. In the F-8 DFBW flight control system experience, low frequency errors such as gyro scale factor error and misalignment caused major difficulties during rapid maneuvers. In the case of large space structure control systems, a form of modeling error which is sure to be present is the neglect of high frequency dynamics. Our work has concentrated on that issue as the probable major source of difficulty in detecting and isolating failures in LSS control systems.

In earlier work we had shown that the methods of Generalized Parity Relations and the Failure Detection Filter are applicable to the FDI function for both sensors and actuators without requiring specification of the possible modes of failure. The generalized parity relations are especially convenient for sensor FDI because individual parity relations can be formed for each sensor - thus providing a single residual function to be monitored for each sensor. Similarly, the failure detection filter seems especially convenient for actuator FDI because the filter can restrict the failure signature for an actuator to a single direction in the output space. Thus, with an appropriate transformation of the output signals, a single residual function can be monitored for each actuator as well.

We also found that sensor failures were much easier to identify against the leakage of unmodeled mode dynamics into the residual than are actuator failures. This is not indicative of a difference between the power of generalized parity relations versus the failure detection filter because if both methods are used to detect both sensor and actuator failures, the signatures of sensor failures are much stronger than the signatures of actuator failures in both cases. So during this reporting period we have concentrated on actuator failures and on the use of the failure detection filter to detect them.

When a failure detection filter is designed to detect and isolate the failures of a number of actuators, this places certain constraints on the parameters of the filter. But in most cases, the designer has complete freedom of choice over the placement of the poles of the filter. The exercise of this degree of freedom has a significant effect on the detection performance of the filter in the presence of unmodeled dynamics. This issue cannot be resolved simply by limiting the bandwidth of the filter to attenuate high frequency unmodeled dynamics. This is not possible because the effect of unmodeled dynamics enters the filter through the measurements which are used directly to form the output residual. Thus the transfer of unmodeled mode dynamics to the output residual is one to one beyond the bandwidth of the filter. Much more complex than this is the fact that the constraints on the filter which cause it to hold failure signatures unidirectional in the output space have a powerful influence on the transfer properties of the filter. As an aid to the study of this issue we have prepared a computer program which calculates the frequency response from an arbitrary structural mode, which might be left unmodeled in the detection filter, to each of the out put residuals which are monitored for actuator failures. We found that with our previous choice of filter eigenvalues, this undesirable transfer was very large at low frequencies where, in principle, the filter has the capability to attenuate the transfer. The amplitude ratio in the low frequency range in some cases was several thousand to one! Although the frequency of the unmodeled mode was beyond the bandwidth of the filter where the transfer was one to one, this high gain at low frequency created a larger problem because of the low frequency content of the unmodeled dynamics due to the forcing inputs.

This problem is now being studied analytically for the case of typical space structure dynamics expressed in modal form. Conditions have been derived which allow some components of the gain matrix to be small. This has resulted in some improvement in the ability of the filter to detect actuator failures, but actuator FDI

remains a more difficult problem than sensor FDI. We are therefore still attempting to find conditions which can guide the designer of failure detection filters to choices of the filter eigenvalues which will enhance the visibility of actuator failure signatures against the background due to unmodeled dynamics. This matter is complicated and progress seems to be coming slowly, but we believe it to be a very important line of research.

The work on system reconfiguration has just begun to make progress. One of the difficulties in attacking this problem is deciding on a suitable set of ground rules with which to work. To illustrate the need for groundrules, we note that one possible approach to reconfiguration would be to design at the outset, not only the nominal control system but also the control algorithm to be used in case of failure of every single component. Given that the control algorithm consists of software to be executed in one or more computers, it is conceivable that the control program corresponding to loss of any one component could be designed and stored in some mass memory device to be called up upon detection and isolation of any component failure. The difficulty with this approach is that following the first failure, one would then have to design the control programs for all possible components which might fail next. Since the design of control systems for large space structures is a very difficult task, this apporach seems inadequate. For the same reason, it seems inadequate to do nothing in advance of the failure and simply redesign the control system "from scratch" after the first failure has occurred. We are looking, instead, for procedures which have a reasonable computational burden which can be executed on board to reconfigure the control system following detection and isolation of a component failure. By a "reasonable computational burden" we allow rather sophisticated procedures, such as solving algebraic Ricatti equations and performing matrix factorizations, but we rule out iterative algorithms with indefinite convergence times.

With some control system architectures, the approach to reconfiguration seems evident. For example, if the system employs a full

order state estimator such as a Kalman filter, reconfiguration following a sensor failure requires redesign of the estimator. Design of a steady state Kalman filter falls within the guidelines for computational complexity cited above. Similarly, if the controller were designed under linear quadratic regulator theory, reconfiguration following an actuator failure requires calculation of the feedback gain matrix for the smaller set of remaining actuators. This too is an allowable task.

But because of the high order dynamic models associated with large space structures, it seems more likely that pactical control system designs will involve reduced order dynamic controllers. In this case it is not at all evident how one should reconfigure. We are addressing this class of problems and are looking first at methods for preserving the closed loop system eigenvalues while making only minimum modifications to the eigenvectors. An objective is to develop algorithms which make the reconfigured system "look" as much like the original system, in some sense, as possible without requiring a statement of the philosophy under which the original system was designed. It is anticipated that simply-described design approaches will not be adequate for LSS control systems and that a certain amount of trial and error may be involved. Thus we hope to reconfigure in a manner that does not depend on the original design approach.

Personnel

The Principal Investigator devoted about 15% of his time to this work during the reporting period. He is still deriving some support from the Hertz Foundation for development of a curriculum on Fault Tolerant Control Systems - which is closely related to our work under this grant. This support will end at the end of this year.

The following graduate students worked full time on the program as Research Assistants:

Alejandro San Martin -- He is working on the FDI task and is successfully applying recent course work on linear algebra to that problem.

Mohammed Massoumnia -- This graduate student took over the reconfiguration task in June when Warren Jasper took employment on the West Coast. Mohammed is one of our brightest doctoral candidates and is beginning to make good contributions to the research. Partly to provide control system designs with which we can illustrate reconfiguration, and partly because it is an interesting problem in its own right, we are investigating previously reported and original methods for designing control systems for large space structures as well as considering how to reconfigure them.

In addition to these students who are being supported by the grant, another doctoral candidate, Michel Floyd, who has support from a Hertz Fellowship, is working on the related subject of control of large space structures using reaction control jets. This involves both theoretical analysis and a demonstration experiment at the C.S. Draper Laboratory. The experimental apparatus is nearly operational now and Michel hopes to finish his work in June.

Publications and Presentations

The paper, "Number and Placement of Control System Components Considering Possible Failures", by W.E. Vander Velde and C. Carignan has been typeset and proofread. It will appear very soon in the Journal of Guidance, Control and Dynamics.

The presentation, "Component Failure Detection in Large Space Structure Control", was given by W.E. Vander Velde at the VPI/SU Conference on Large Space Structure Dynamics and Control in Blacksburg, Virginia, in June. The paper will appear in the proceedings of that conference.

END

DATE

FILMED

MAR 22 1984